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About the structure and development of the gadid tooth
(A contribution on the knowledge of the vasodentine)

H. Fischer

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(Ein Beitrag zur Kenntnis des Vasodentins)

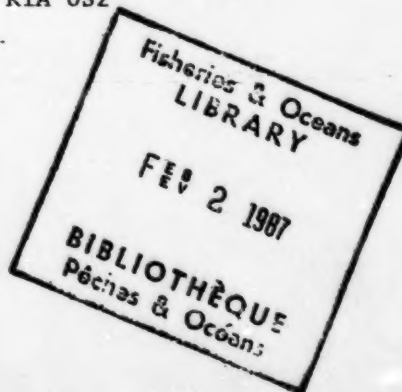
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About the Structure and Development of the

Gadid Tooth¹⁾.

(A Contribution on the Knowledge of the Vasodentine).

By Hans Fischer.

With 14 text figures.

(Received November 12, 1937).

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1) Inaugural dissertation of the Faculty of Medicine of the University
of Zürich, carried out under the direction of Docent Dr. W. BARGMANN.

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Introduction.

The comparative-morphological investigation revealed the existence of many types of dentine which are found mainly in the family of fishes. A special, ultimately confusing terminology has been invented to deal with the structural characteristics of the dentine (see LEHNER & PLENK 1936; there is also the list of histological terminology for hard substances of the tooth by PEYER 1937), so that we presently speak of osteodentine, trabecular dentine, vasodentine to name only a few. Although the orderly differentiation of the various types of dentine may have been necessary, this has resulted in an unrelated hodgepodge collection of dentine forms rather than in an active understanding of these tissues under a guiding viewpoint. Attempts to study particularly the general aspects are welcome therefore, so that a consistent concept can be reached of the nature of the hard substances of the teeth, as indeed of all hard substances of the vertebrate body, under consideration of histological and paleontological findings (PEYER 1937, WEIDENREICH 1930). RÖSE already assigned the leading role in the odontology to the histogenesis; he was followed by WEIDENREICH who coined the histogenetic-histological terms "mantle dentine" and "circumpulpal dentine" and thus prepared the way from the dental histology to the science of the microstructure

of the bone; he also endeavored to view and treat the problems of the dentine structure and dentine development as problems of hard substances. WEIDENREICH compared the coarse-fibrous mantle dentine with fibrous bone, the fine-fibrillar circumpulpal dentine with membranous bone. As PEYER (1937) excellently demonstrated in his manual recently, one may in principal or in particular instances disagree with WEIDENREICH's general concept and particularly with his notion about the enamel "being a specially differentiated external layer of the dentine" and thus ultimately a type of bone; a concept which this author cannot accept either. It has been shown however, that it is possible to verify the validity of these concepts at least in the area of the structural science of the dentine; thus the trabecular dentine (RÖSE) of the tooth plates in Chimaera monstrosa can be analysed as mantle dentine, the compact filling material between its trabeculae as circumpulpal dentine (BARGMANN 1933). The next step was obviously to study the microstructure of another conspicuous type of dentine, the vasodentine, and to determine whether it can be easily integrated into WEIDENREICH's categories. WEIDENREICH (1930) himself already pointed out the necessity of investigating this type of dentine. Clearly, such an investigation could not be limited to the study of the vasodentine alone, since the various differentiations of the dentine, such as mantle and circumpulpal dentine, are fused into an inseparable entity. Consequently, an analysis of the entire gadid tooth was called for, taking into account a number of questions concerning the dental histology which are of general odontological interest, as i.e. the controversial questions of the involvement of v. KORFF's fibers in the formation of the dentine, and others.

The concept "vasodentine" emerged for the first time in the mid-1900s. OWEN (1840-45) treated it as a collective term for various types of dentine traversed by vessels. CH. TOMES (1878) later corrected OWEN's concepts and limited the term vasodentine exclusively to dentine which is tubule-free but traversed by numerous blood vessels such as he observed in the cod (Gadidae). TOMES noticed a reddish tinge on the teeth of live cod fish, an observation which induced him to undertake a closer investigation. After TOMES, RÖSE (1898) returned to the vasodentine in his general studies of hard tissues. His test object was Merlucius vulgaris. RÖSE found that the capillaries in the Merlucius tooth become entirely imprisoned by the growing dentine and attributed to them the role of nutritive organ for the finished tooth. In RÖSE's view, the odontoblast processes in the gadid tooth have the tendency to degenerate and the capillaries vicariously seem to take on the role of the cell processes. OWEN's vasodentine was called osteodentine by TOMES, and the latter in turn was called trabecular dentine by RÖSE. RETTERER (1926) investigated the vasodentine of Gadus carbonarius and Trochocopus darwini; he only provided a short synopsis of the topographic properties of the vasodentine layer in the tooth. THOMASSET (1928) in his classification of the dentine types in fishes touches briefly on the theme vasodentine without giving exact details on its microstructure. To summarize: the information and pictorial documentation available as yet on gadid teeth and their vasodentine is inadequate and fragmentary. It has to be pointed out that the vasodentine in question is a normal formation and is not to be confused with the vascular dentine of mammals which

is the result of pathological processes. ADLOFF (1930) already emphasized that mammal teeth lack true vasodentine.

I. Material and Technique.

The present investigations cover the following representatives of teleosts: Gadus morrhua, Gadus merlangus, Gadus minutus, Gadus luscus, Merlucius vulgaris, Phycis blennoides. I thank the Zoological Station Naples and Dr. E. SCHARRER, Frankfurt a.M., for the assistance in procuring the material. Fixation: 10% Formol, Susa, Bouin. Decalcification with 5% Nitric Acid..Embedding: Methyl Benzoate-Celloidine-Paraffin after PÉTERFI. Paraffin sections were stained or, respectively, impregnated with Azan, after BIELSCHOWSKY-MARESCH, with Gentian Violet (WEIGERT-WEIDENREICH). Finally, a number of observations were carried out on non-decalcified, entire teeth, cleared in Benzol; furthermore, razor sections and ground specimens embedded in Glycerin Gelatin, Glycerin or in concentrated Canada Balsam. Fat staining of frozen sections: Sudan III.

II. Results.

a) General Observations on Form and Structure of the Gadid Tooth.

The teeth in the investigated species are generally of conical shape. Their size varies in correspondence with the body size of the fish. Thus, a functioning, fully developed tooth in the small Gadus minutus measured lengthwise is ca. 1.5 mm. The largest teeth of Gadus morrhua I could find measure 10-12 mm. The teeth sit on the dentary bone or

in folds of the mucous membrane in the immediate proximity of the jaw bone and also on the pharyngeal bones. The gadids are predatory fishes and their teeth serve to grasp and hold the prey. This explains the slight recurvation of the teeth. A dentine cone and an enamel cap can be identified in the tooth (figs.1, 2 and 14). Entire teeth, which had been cleared in Benzol, studied with a magnifying glass; or the microscopic study of sections and ground specimens under low magnification, reveals in the interior of the tooth a well developed capillary system which in its entirety has a coniform outline corresponding to the shape of the tooth (fig.2). Toward the surface of the tooth, the network of capillaries terminates with a system of arcades, the convexities of which are oriented toward the periphery of the cone (fig.2). Cross sections through the basal parts of older teeth, particularly in Gadus morrhua, display a remarkably uniform arrangement of capillary loops (fig.3). Longitudinal sections often reveal a rope ladder-like pattern. The vasodentine is most distinctly developed in Gadus morrhua. The tooth is anchored to the substrate by means of a base formed by the bone, on which the tooth rides. A ligament further reinforces this connection considerably. It seems that teeth, which initially are loosely embedded in the mucous membrane adjacent to the bone, later may become firmly attached to the substrate by means of bony tissue. The fine structure of this anchorage will be discussed later.

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Fig.1: Tooth of Gadus morrhua, non-decalcified, embedded in Glycerin Gelatin. Note the dark enamel layer, circular lines in the area of the enamel, dentine lamellae. Magnification ca. x140 (reduced to 3/4).

b) Histogenesis of the Mantle Dentine.

The formation of the gadid tooth follows the known basic pattern of tooth development. RÖSE (1894) intimately studied the tooth formation in fishes in general and established two different developmental stages: A first placoid stage and a second trabeculate stage which differs substantially from the former; in the latter, an epithelial strand grows into the depth to start tooth formation, while in the placoid stage the entire mucous membrane is capable of forming teeth. In my specimens, I invariably found a well developed dental ridge. I cannot comment on the placoid stage, which according to RÖSE is found only in embryos, since I exclusively investigated adult fishes.

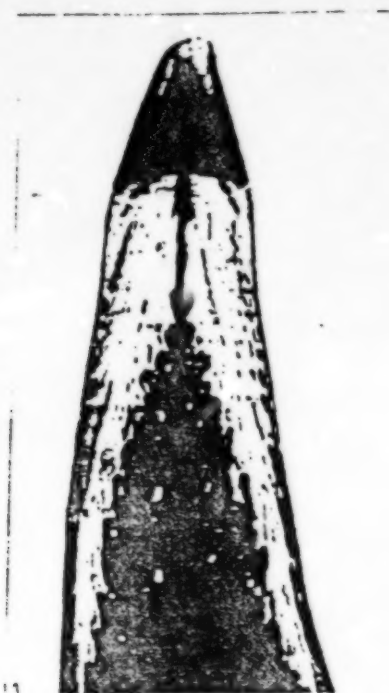


Fig.2: Tooth of Gadus morrhua, cleared in Benzol, embedded in thick Canada Balsam, capillary system of the vasodentine appears black. Enamel layer dark. Magnification ca. x150 (reduced to 3/4).

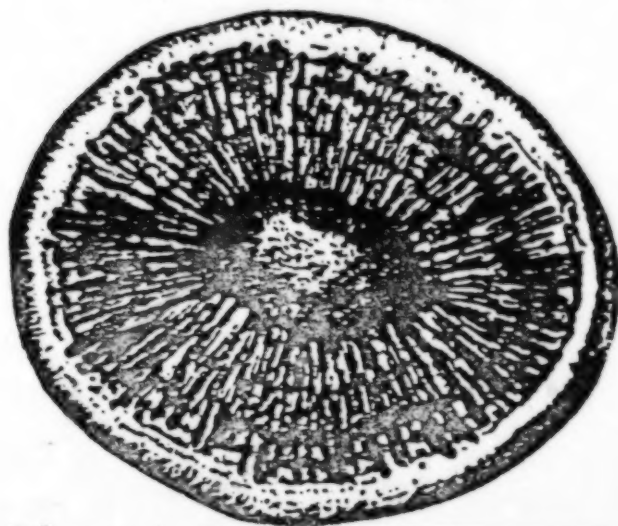


Fig.3: Tooth of Gadus morrhua, decalcified, razor cross section, unstained. Hairpin loops of the capillaries of the vasodentine, mantle dentine on the periphery. Magnification ca. x110 (reduced to 3/4).

Already in very young dental cap stages or, respectively, bell-shaped stages, distinct concentrations take place in the mesenchyme beneath the epithelium, indicating its correlative growth in the sense of v. EBNER (1922) and W. MEYER (1932). In the further course of development, the elongate odontoblasts at the periphery of the dental papilla can be seen to differentiate and form an epithelium-like layer. Between enamel epithelium and tooth papilla occurs the membrana preformativa as ^aweakly blue stained layer in the Azan preparation. The odontoblasts display the cytoplasmatic granulations described already by other experimenters which play perhaps a role in secretory processes. The process of formation of the hard substance is initiated by the occurrence of very delicate, wavy strands of fibrils between enamel epithelium and odontoblasts, as shown in fig.4 in a tooth bud of Merlucius. These fibrils, which are part of the eventually developing dentine, are oriented tangentially to the surface of the odontoblast layer, and at the tip of the mesodermal part of the dental bud form a fibrillar plait (fig.4); this can be traced through numerous sections and is therefore not a misinterpreted section through the fibrillate membrana preformativa. Preparations impregnated with silver show that it is a matter of precollagen fibers. According to new investigations by ERAUSQUIN (1935) carried out in the laboratory of Del Rio Horteiga, in dental buds of mammalian embryos there also occur precollagen fibrils as constituents of the future dentine. A parallel to these results can be found in the histogenesis of bony tissues whose early stages can be recognized in the form of concentrations of fibrils surrounded by osteoblasts. As seen already in the younger dental bud shown in fig.4, but even more so in older stages (fig.5), there is clearly a connection

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between the fibrils in the mesenchyme of the dental pulp and the mentioned tangentially oriented fibrils. The pulp fibrils spread out radially into the periphery of the coniform bud where they, meandering between the odontoblasts, bend into the tangential direction. This situation can be seen particularly clearly in the basal half of the dental bud. The pulp fibrils also receive additional small fibers from the connective tissue of the dental sac, as was described already by WEIDENREICH. There is no reason therefore, to doubt the existence of v. KORFF's fibers. On the basis of my results I disagree with recent statements by LEHNER & PLENK (1936) that the fibrillar structure of the first dentine layer can be explained by the "unavoidable incorporation of the reticular-fibrous membrana preformativa", and that v. KORFF's fibers only represent "coniform processes of predentine character".

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It may be concluded that with regard to the behavior of v. KORFF's fibers, the gadid teeth represent a special case which is not generally applicable. However, detailed investigations of the mammalian and human tooth by ERAUSQUIN (1935) and SANTONÉ (1934) yielded basically the same results. In the adult human tooth can also be seen a continuous cohesion of pulp fibrils and dentinal fibers, with the connective fibers passing through the odontoblast layer.

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It is difficult to visualize the development of the cohesive fibril network and the mechanism of their typical alignment at the surface of the odontoblast layer. It is unclear furthermore, whether the precollagen fibers are formed by the odontoblasts or by the mesenchyme cells (SANTONÉ). v.KORFF (1932) stated that the pulp fibrils are independent, propagatory structures which are embedded in a substance secreted by the odontoblasts. However, the experience gained from cultures of live, explanted tissue does not enable us as yet to conclude that fibrils can develop without the



Fig.4: Tooth bud of Merluccius vulgaris, Azan staining, 9 μ . Fibril plait between enamel epithelium and odontoblast layer. Magnification ca. x700 (reduced to 9/10).

participation of cells. Moreover, fibrillar precursors of bone or the predentine layer are invariably found only in the presence of mesodermal cell elements; I am inclined therefore, to ascribe to the odontoblast layer not only the task of producing a matrix but also of participating in the development of the fibrils, which appear already prior to the occurrence of the cement substance. A topographically intimate relationship between odontoblasts and fibrils exists inasmuch as the dentine-forming odontoblasts at the edges of the inverted dental egg-cup possess long TOMES's processes which run between and parallel to the collagen fibrils. These processes no longer exist in the middle

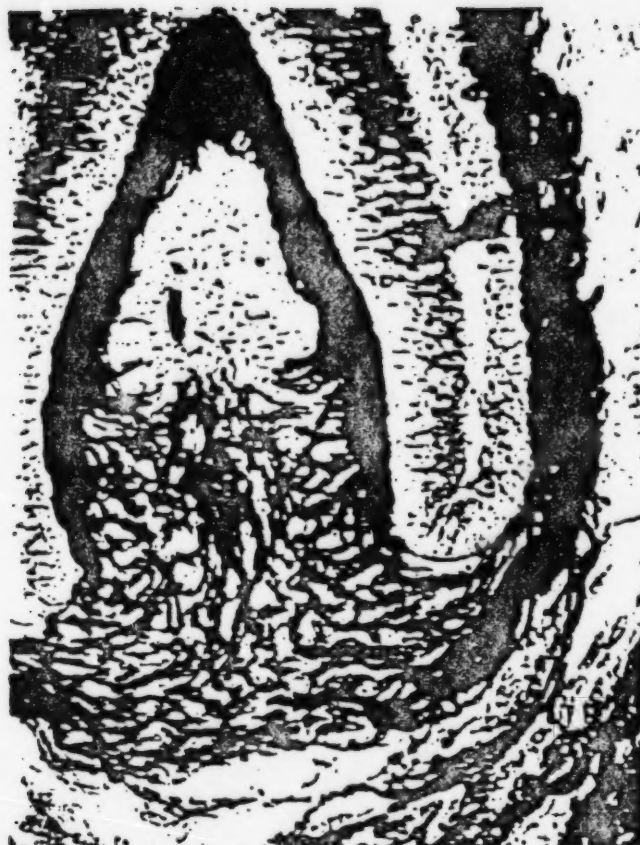


Fig.5: Tooth bud of *Merluccius vulgaris*, silver impregnation after BIELSCHOWSKY-MARESCH, 8 μ , fibrillar structure of the predentinal layer, continuity of the predentinal fibrils, pulp fibrils and fibers of the dental sac. Magnification ca. x700 (reduced to 9/10).

and apical parts of the dental bud. A study of successive series of sections shows how these processes, after detaching from the cell body, gradually fade away in the predentine. It could be observed indeed, that here and there individual processes still maintained a connection with the cells, while others in the immediate vicinity had already lost all contact. The described first stage in the dentine production, which largely resembles the known process of the development of fibrous bone, results in the formation of the compact outer zone of



Fig.6: Tooth of Gadus morrhua. Sagittal section, fiber staining with Gentian Violet (WEIGERT-WEIDENREICH), 9 μ . Note the coarse fibers of the mantle dentine. Magnification ca. x650 (reduced to 2/3).

the finished tooth which we will call mantle dentine after WEIDENREICH. Sections through fully-grown teeth stained with Gentian Violet clearly show the longitudinally running strands of sturdy fiber bundles (fig.6), and their composition of fibrils is particularly evident on cross sections (fig.7). In the specimen of fig.6, the fibers were artificially separated in one place specifically to demonstrate the fibrous structure of the mantle dentine. In the Azan preparation, the dark red staining of the fiber strands of the mantle dentine is evidence of calcium salt deposits in the fibers. The mantle dentine does not display any vascular system comparable to the dentinal tubuli nor any inclusions of odontoblasts or their processes. The theory is that its formation takes place rhythmically. This assumption is supported by the fact that a formation of lamellae can be seen in total preparations of cleared teeth (fig.1). The lamellae are particularly noticeable in

the apical area. The mantle dentine could be seen as a layer consisting of funnels of hard substance which are inserted into each other. To judge from the staining pattern, some lamellae seem to be calcified to a larger, others to a lesser degree.

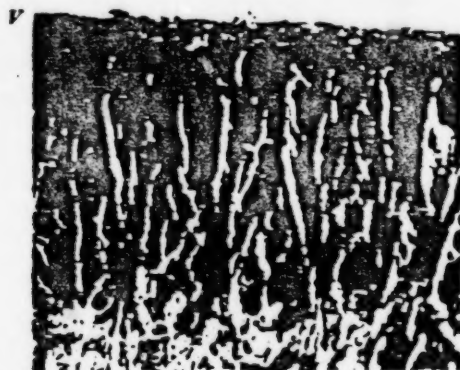


Fig.7: Tooth of Gadus morrhua, cross section, 9 μ , same staining method as in (6). The coarse-fibrous mantle dentine zone is adjoined toward the outside by the vitrodentine zone (V). Magnification ca. x650 (reduced to 3/4).

c) The Vitrodentine.

The outer zone of the mantle dentine is adjoined by a narrow layer lacking cells as well as coarse fibers which is named vitrodentine in the literature. The investigation of the fully-grown tooth shows that the vitrodentine deserves its name on account of its hardness and transparency; it resembles the enamel in its physical properties. In preparations stained with Gentian Violet and Azan can be seen very fine fibrils in the vitrodentine which are embedded in a matrix (see BARGMANN, 1937). The calcification of the vitrodentine is not entirely uniform inasmuch as its periphery is substantially more heavily calcified than the layer adjacent to the typical mantle dentine. Sudan staining of frozen sections shows up the vitrodentine

as delicately orange tinted band. Whether this phenomenon is due to the deposition of fatty substances, which can be expected to be present on the basis of findings in the bone and tooth histology (BARGMANN 1934), could not be conclusively determined. The vitrodentine doubtlessly represents that part of the hard substances which is laid down first during development. Its system of fibrils is possibly identical with the fibrillar network of the membrana preformativa which, according to LEHNER & PLENK (1936), is incorporated in the dentine formation. However, the observations on the tooth plates of Chimaera monstrosa (BARGMANN 1933) indicate that in this case the vitrodentine represents a surface differentiation of the mantle dentine. Its nomenclatorial accentuation as vitrodentine should perhaps be changed to "outer zone of the mantle dentine".

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d) Histogenesis and Microstructure of the Vasodentine.

The development of the vasodentine, which is particularly easy to observe in Gadus morrhua, begins only after a considerable layer of mantle dentine has been laid down. In the border zone between mantle dentine and dental pulp, there first occur blood vessels, particularly at the basal edge of the tooth bud, which lie closely apposed to the predentine and are later entirely enveloped by it. They represent thin-walled capillaries furnished with a reticular-fibrous membrane and accompanied by a thin layer of mesenchymal elements (fig.8). Between endothelium and the hard substance is a thin, narrow interspace which is occupied by the mentioned associated cells.

The already partially or entirely imprisoned capillaries are connected with the richly developed vascular system of the dental pulp; they already show the typical arcade-like and rope ladder-like arrangement described previously. The pulpward oriented surface of the capillaries is covered by a continuous layer of odontoblasts. The curved path of the capillaries through the odontoblast layer into the dentine can be observed in many places. The older the tooth, the thicker is the dentine mass traversed by the capillaries (fig.3). On account of its structure, the hard tissue surrounding the capillaries is not identical with the mantle dentine. Strong fiber strands as shown in figs.6 and 7 are lacking. Preparations stained with Azan and Gentian Violet reveal instead very thin fibrils which usually run in the longitudinal direction of the tooth and are embedded in a finely granular matrix. These fibrils are often barely recognizable. Cell inclusions do not occur in the vasodentine.

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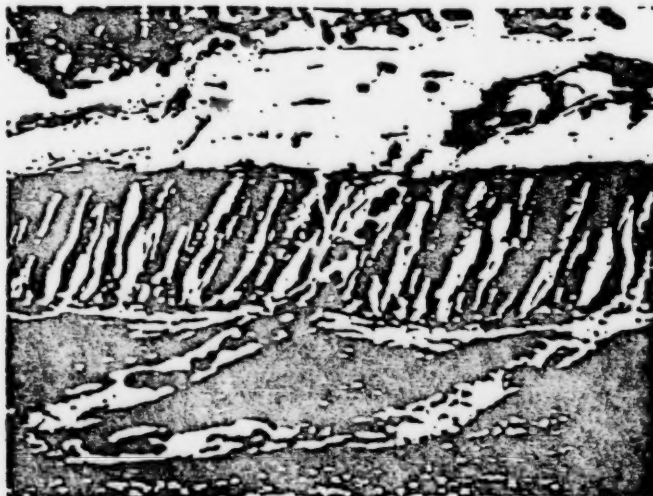


Fig.8: Tooth bud of Merlucius vulgaris. Sagittal section, Azan, 10 μ . The odontoblast layer is traversed by a capillary coming from the dental pulp. At (V) vasodentine. Magnification ca. x1100 (reduced to 1/2).

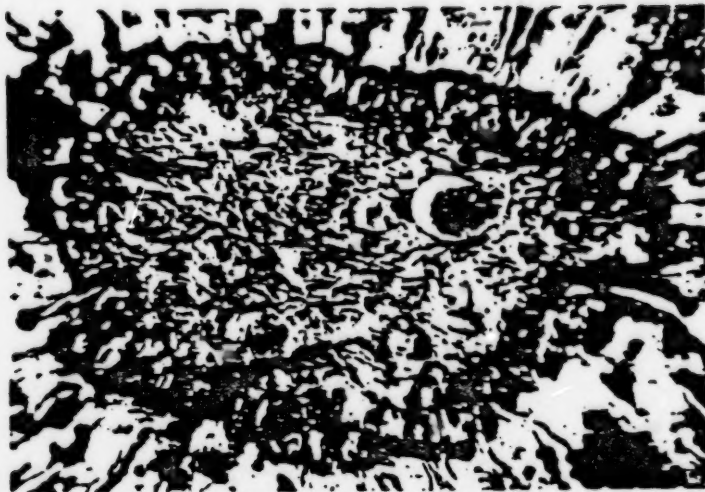


Fig.9: Tooth of Gadus morrhua, cross section, Azan, 11 μ . Dental pulp. The pulp shows a peripheral, cell-deficient and a central, cell-richer part. Magnification ca. x300 (reduced to 2/3).

The inclusion of capillaries in the dentine basically may take place in two different ways, either by embedding of the preexisting capillary system, or by the invasion of vascular processes eating their way into the dentine, so to speak. In the latter case there would be evidence of perforations in the dentine as well as osteoclasts in association with the capillaries. However, I have never observed any signs of an active migration by the capillaries; therefore I tend to regard the presence of capillaries in the dentine as a passive process. The odontoblasts represent the active element; in secreting the matrix, they come to lie increasingly nearer the center, while the capillaries, in the spatial sense, remain on the spot and become imprisoned parallel to the tempo with which the matrix is produced. I noticed that in the immediate vicinity of the entrance points of the capillaries, which are oriented in all directions, the odontoblasts are always approximately parallel-aligned to the axis of the respective

capillary. This supports the supposition that the odontoblasts, which at first are radially aligned to the dental pulp, subsequently orient themselves parallel to the capillaries. I could not determine from my preparations whether and in what manner the odontoblasts, apart from their secretory activity (see ERAUSQUIN), also participate in the formation of the fine fibrils of the vasodentine. However, I assume the latter to be the case since the odontoblasts are seen to send out processes which proceed in a vertical direction to the longitudinal axis of the cell body, that is they are deflected, and in a thin layer are closely applied to the inner surface of the newly forming dentine layer. WEIDENREICH (1925) apparently failed to see these processes. The described imprisonment of the capillaries has its parallel in the histogenesis of the circumpulpal dentine of Chimaera monstrosa (BARGMANN 1933). Here, various form elements of the dental pulp tissue become embedded in a finely-fibrillar hard tissue.

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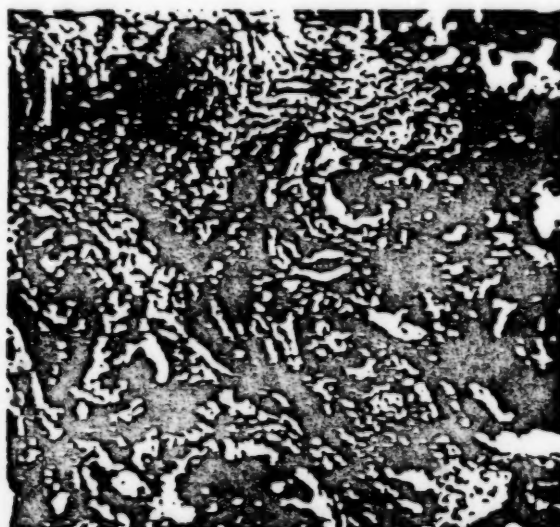


Fig.10: Detail from fig.9. Dental pulp tissue in the process of transformation into hard substance. Inclusion of dying cells. Magnification ca. x550 (reduced to 3/4).

A similar situation concerning not only the embedding of blood vessels but also the integration of dying dental pulp cells and coarse, connective tissue fibers, can be seen perfectly in large, fully-grown teeth of Gadus morrhua. In cross sections through the dental pulp (fig.9), a central, cell-rich zone can be distinguished from a cell-poorer zone, stained pale blue in the Azan preparation, which adjoins the inner surface of the vasodentine. In the border region between vasodentine and the cell-deficient tissue lie clusters of mesenchymal cells and odontoblasts in roundish complexes. Under higher magnification, the cell-deficient areas are seen to consist of delicate fibrils (fig.10) which are apparently bonded together by a finely granular cement-like substance (perhaps secreted by the odontoblast clusters). In the faded looking fibrillar tissue occur disintegrating cells and cell debris, also capillaries which communicate with those of the vasodentine. Small calcification zones are visible here and there. This process represents the formation of a hard tissue which by means of the fibrils is continuously interconnected with the vasodentine as well as with the central pulp areas and merges fluently with them. On the basis of these results I feel justified in stating that the vasodentine represents a special form of the circumpulpal dentine.

RÖSE regards the capillaries of the vasodentine as equivalent to the odontoblast processes not embedded in the dentine. This concept has a certain validity since analogies do at least exist between the walls of the vascular canals of the vasodentine and the dentinal sheaths of NEUMANN. In Azan or Gentian Violet preparations, the wall of the vascular canal, similar to NEUMANN's sheath, appears as dark red and

violet stained tubule and is distinct from the surrounding dentinal matrix, comparable to the sheaths of the dental pulp canals found in pike teeth by WEIDENREICH (1925). Such sheaths, although of far more delicate and less regular fibrillar structure, can be seen also in Gadus. What role the embedded tubules play in the gadid tooth must remain unanswered. It can be assumed that the presence of a blood-filled vascular system in the dentine facilitates the diffusion into the dentine of substances carried in the blood, i.e. calcium salts. In some distance around the vascular canals of young teeth can be seen a distinct calcium deposition in circular zones which in older teeth may extend up to the wall of the vessel. The development of a canal system with firm walls contributes perhaps to the mechanical strength of the tooth.

e) The Attachment of the Teeth.

In view of WEIDENREICH's (1925) description of the anchorage of the Gadus morrhua tooth, I limit myself to comment briefly on the connection between bony tissue and dentine. It is easy to determine that the Gadus teeth are not rigidly anchored on or in their substrate, but show a certain movability. This movability is brought about by a ligament connecting together the bony tissue and the hard substances of the tooth; the ligament consists of densely packed, parallel-running collagen fibers. The fibers run from the dentine into the bony tissue. When they become occasionally calcified, which occurs in older teeth, then the transition between the two tissues is fluent. The bony tissue of a Gadus jaw is an osteocyte-free but distinctly

lamellated hard tissue the laminae of which are grouped around cavities containing vessels and filled with a reticular connective tissue. There is thus a certain similarity with the lamellated structure seen in bony tissue of higher vertebrates. In the bony tissue parts adjacent to the dental base there is less or no evidence left of the lamellate character, instead the bony tissue here is traversed by numerous vessels and its marrowed cavities communicate with the pulp cavity. In the transitional zone between bony tissue and dentinal tissue it is therefore difficult to demarcate the vasodentine sharply from the bony tissue (fig.11). On the basis of this fact, the homologizing of bony tissue and dentine seems quite plausible.

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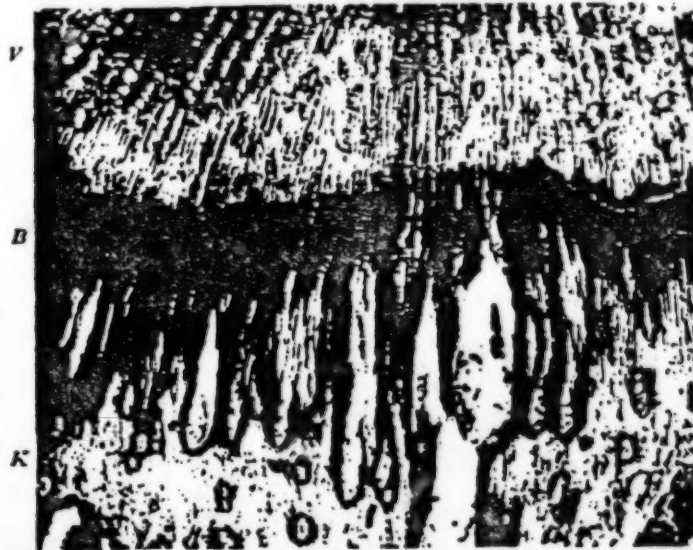


Fig.11: Tooth base of *Gadus morrhua*, sagittal section, Azan, 10 μ . K = bone, B = ligament, V = vasodentine. Magnification ca. x300 (reduced to 3/4).

As indicated at the beginning, the formation of a bony tissue bar which is continuous with the dentine, in older teeth may bring about a rigid anchorage to the jaw bone (see fig.79 in B. PEYER 1937).

f) The Enamel.

Figs.1, 2, 14 demonstrate the extent of the enamel which sits in the form of a cap on the tooth cone. The enamel layer is distinctly hollowed out to facilitate its firm anchorage on the dentine cone. In the intact tooth, the enamel is readily recognizable on account of its bluish white color. Following burning out of a tooth, the enamel layer retains its shape unchanged. After treatment with acid, the enamel disappears completely. I have experimentally decalcified human and gadid enamel simultaneously in the same acid and found that the effect in both is the same. Therefore the percentage of anorganic substance probably is approximately the same. In the polarization microscope the finished enamel is negative double refractive. The investigation of entire, occasionally cleared teeth reveals the presence of rings on their surface in the area of the enamel layer (fig.1) which may have their origin in the rhythmic formation of the enamel cap. The presence of enamel prisms could not be established, but that does not mean that the enamel is to be regarded as a homogeneous substance. The observation under the microscope of the decalcification process of an entire tooth shows that after the enamel layer has disappeared, there remains a stringy-slimy residue underneath the enamel surface membrane.

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In paraffine sections it can be seen that the border line of the dentine toward the enamel is never smooth and evenly curved but zigzags or ends in frayed arcades which is probably caused by dentine fibers crossing into the enamel.

The presence of an enamel surface membrane can be easily demonstrated in the teeth of Gadus morrhua. The microscopic observation of the decalcification process of a tooth in Nitric Acid reveals that the membrane is not destroyed by the acid but remains behind as the contour of the hard substance cone, so to speak. With respect to the demonstration of the enamel surface membrane, the Gadus tooth represents an ideal object for teaching purposes.

g) "Stress Lines".

After staining entire, non-decalcified teeth of Gadus morrhua for 1 to 2 hours in diluted Hematoxylin, a peculiar system of lines can be seen on the tooth surface, the course of which is shown in figs.12, 13, 14. To reach the proper idea of their arrangement, figs. 12 and 13 should be viewed in combination. On fig.12 can be seen numerous lines coming from the buccal side, which apparently radiate from a center and run up the tooth toward the apex where they unfold very evenly and symmetrically. These lines run to the distal or, respectively, mesial side of the tooth (fig.13), where they form an arc, and from there to the lingual side, again resulting in the pattern seen in fig.12. A roughly similar pattern is obtained in oblique sections through the cone. In numerous stained and unstained teeth the same or similar line patterns could be observed which give the impression of fine fissures. The same lines could also be demonstrated with Aniline Blue (fig.14), 2% Silver Nitrate solution and various other stains. Following Aniline Blue staining, the lines appeared pale on a blue background. With regard to the course pattern, these lines in a purely formal sense recall the trajectory-like structures found on the



Fig.12



Fig.13

Figs.12 and 13: Tooth of Gadus morrhua, total preparation. Line system rendered visible with Hematoxylin stain. Magnification ca. x150 (reduced to 2/3).

elephant tusk by GEBHARDT (1900) which are caused by ontogenetically laid down patterns of arrangement of dental tubules and fibers. But the investigation of my material failed to reveal any evidence that the described line systems are in any way related to the histologically determinable structure of the teeth, or that they could be regarded as growth architecture and simultaneously also as functional structures. Their appearance strongly indicates that it is indeed a matter of fissures in the surface layer of the dentine, more precisely in the vitrodentine. It is characteristic that the enamel layer is free of such lines (fig.14).

p.741



Fig.14: Tooth of Gadus morrhua. Total preparation, Aniline Blue. Pale lines on dark background. Enamel layer pale. Magnification x160 (reduced to 2/3).

Which factors could be responsible for the development of such a line system? It suggested itself to look at these peculiar findings from the technical viewpoint, specifically from the aspect of the theory of strength (PÖSCHL 1936), to find a possible explanation for this phenomenon. To briefly recall the topographic-histological situation of the Gadus tooth: it consists of two types of hard substances, a) the actual dentine core with the capillaries and the prominent fiber strands in the mantle dentine; b) the surface crust consisting of the enamel layer and the vitrodentine, that narrow enamel-like outer zone of the mantel dentine. Relating the mentioned dental hard substances to industrial materials of the technique, the comparable counterpart to the dentine is reinforced concrete, a material

which resists pressure and pull. The pressure resistance is furnished by the concrete (basic substance of the dentine), the tensile strength by the embedded iron rods (longitudinal fibers in the mantle dentine). To a certain degree the vitrodentine can be regarded as homogenous mass; as the name indicates, it resembles a glaze or lacquer and accordingly is brittle.

The individual tooth is exposed to forces of various strengths and directions. In correspondence with its function as barbed hook, it is subjected to tensile forces. Its concave side is under tensile stress, its convex side under compressive stress. The central areas of the tooth containing pulp and vasodentine can be regarded as neutral zones. The mantle dentine, which is assumed to be responsible for tensile and compressive resistance, can undergo deformation without disruption of continuity, while the external layer, the brittle vitrodentine, occasionally shows cracks similar to the enamel layer in human teeth. The technologist speaks of cleavage fractures along main stress lines. It has to be mentioned however, that apart from the mechanical stress, other factors such as desiccation or temperature fluctuations may be responsible for such fissures. For external reasons, it was unfortunately not possible to investigate fresh Gadus teeth with respect to the presence of the described lines. In view of the hypothetical character of these comments, we are limited for the time being to regarding the occurrence of these "stress lines" as confirmation of our histological concepts of the nature of the vitrodentine as outer layer of the dentine resembling the enamel in its physical-chemical makeup.

III. Summary of Results.

A summary of the essential findings leads to the following results:

1. The formation of the dentine in the tooth buds of the gadid teeth begins with the development of argyrophilous fibrils between dental papilla and enamel epithelium. These fibrils are in continuous communication with those of the future dental pulp; furthermore, there is a connection between the argyrophilous fibers of the dental sac and those of the dental papilla or, respectively, dental pulp. Contrary to LEHNER & PLENK (1936), the existence of the so-called v. KORFF's fibers has to be retained. The processes of the odontoblasts and the dentine fibrils in the youngest dentine areas run parallel to each other; the cell processes later vanish in the hard substance.

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2. In the gadid teeth, a peripheral zone can be distinguished which corresponds to the so-called mantle dentine; it consists of coarse fiber bundles bonded together by a cement substance. The thin outer layer of the mantle dentine displays the characteristics of the vitrodentine. The mantle dentine consists of hard substance funnels which are inserted into each other.

3. The principal mass of the gadid tooth consists of vasodentine; it is formed, not by capillaries invading the dentine, but by the imprisonment of a preexisting capillary system of the dental pulp in a finely fibrillar dentine. With advancing growth of the tooth, large parts of the dental pulp are incorporated in the vasodentine layer accompanied by the destruction of the imprisoned cells. The vasodentine can be regarded as a special form of the circumpulpal

dentine. At the tooth base, the transition of the vasodentine into the lamellate, cell-free bony tissue of the jaw is often continuous.

4. The enamel cap of the gadid tooth is covered by an isolable enamel surface membrane. The enamel substance is not build up of prisms, but may nevertheless not be regarded as homogenous mass. The dentine fibers seem to radiate into the enamel.

5. The staining of entire non-calcified teeth of Gadus morrhua with Hematoxylin or Aniline Blue reveals a system of lines on the dental surface which can be traced to fissures in the glazelike vitrodentine layer and are perhaps caused by stress conditions.

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